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Editorial

Three-dimensional echocardiography: new views from old windows

A wide range of techniques for cardiac imaging developed rapidly as a consequence of advances in computer technology and changing clinical perspectives. Cardiac ultrasound is one of these and has largely achieved its promise as a comprehensive diagnostic imaging tool. Because it introduced new pathophysiological concepts, did not replicate existing diagnostic methods, and contributed significantly to the understanding of cardiac disease, cardiac ultrasound has become, in two decades, the most widely used diagnostic imaging technique in clinical cardiology. Objective imaging of the heart in all its dimensions has been an important research goal since the introduction of tomographic imaging techniques, such as echocardiography, computed tomography, magnetic resonance, and positron emission tomography. Such imaging would overcome the difficult mental process of conceptualising this complex structure from multiple cross sectional images. It would allow us to study complex pathology and structures of unknown geometry.

There have been two main approaches to three-dimensional reconstruction. One was the wire-frame or surface rendered reconstruction of selected structures, such as the left ventricle, from manually derived contours in tomographic images that give spatial information.[1] Though this approach allows measurement of ventricular volumes and the study of the shape of the structure, it does not give important information about the tissue (as a grey scale). The data processing algorithms that have recently become available for volume rendered reconstruction provide grey scale tissue imaging and represent a major breakthrough.[2]

The possibility of on-line acquisition of three-dimensional data by means of novel phased array transducer technology is being investigated, but progress is slow and its clinical application seems remote.[3]

The acquisition of a consecutive series of cardiac cross sections on standard available ultrasound equipment and retrospective off-line three-dimensional reconstruction is currently a more practical approach. However, the simultaneous registration of the accurate spatial position and timing of the sequentially acquired cross sections is a major technical challenge. Positional information has been obtained with a mechanical articulated arm or acoustic (spark gap) or a magnetic location system that allows unrestricted scanning from any available precordial acoustic window by standard imaging transducers.[4] However, linear (pull back), fan-like, or rotational scanning techniques using a predetermined geometric acquisition pattern allow the recording of more closely and evenly spaced cardiac cross sections. This is essential if interpolation algorithms are to be used to fill the gaps between the original cross sections throughout the image data set and to preserve the grey-scale information for volume rendered reconstructions.[5] These acquisition techniques can also be used transoesophageally, allowing the recording of high quality cross sectional images in virtually all patients studied. However, the transducer assemblies for linear scanning are rather bulky and do not allow the necessary manipulations of the probe within the oesophagus to obtain detailed imaging for diagnostic purposes. They have to be introduced after a diagnostic study, which prolongs the procedure and slightly increases the risk. Probe assemblies for linear

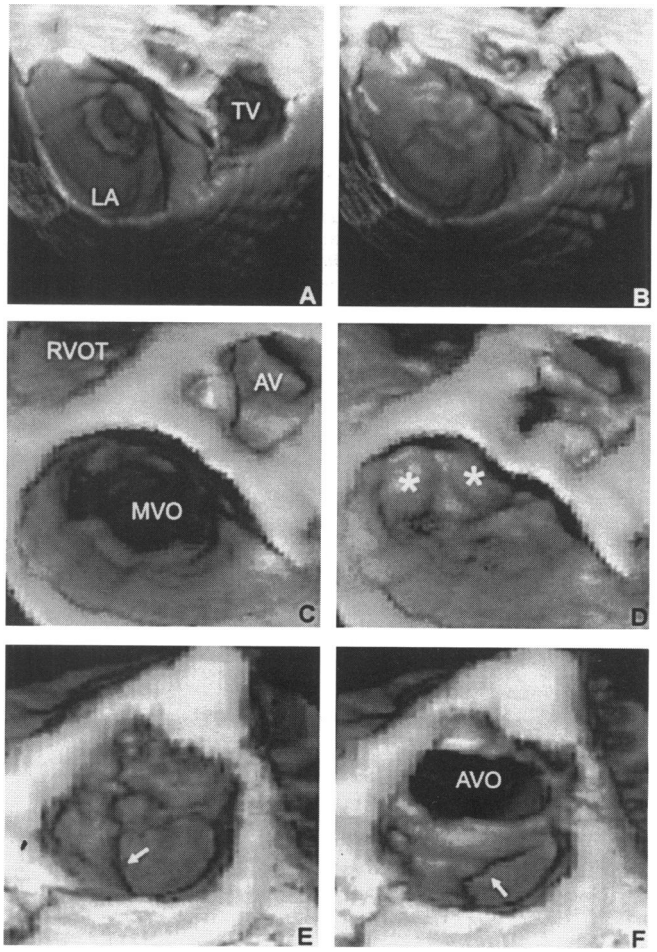

Figure 1 Examples of volume rendered three-dimensional reconstructions of mitral and aortic valves. (A and B) Atrial views of the atrioventricular valves in a patient with mitral stenosis. (A) Note the extremely dilated left atrial cavity (LA) with corrugated walls, the open stenotic mitral valve and the normal sized right atrium and tricuspid valve (TV). (B) During systole the valves are closed. (C and D) Atrial views of a patient with prolapse of the anterior mitral valve leaflet (asterisks). The aortic valve (AV) is shown in closed position in diastole (C) and in open position in systole (D). MVO, mitral valve orifice; RVOT, right ventricular outflow tract. (E and F) A congenitally bicuspid aortic valve visualised from above in closed position (E) and in open position (F). The arrow indicates the raphe produced by fusion of the left and right coronary cusps (arrows). AVO, aortic valve orifice.

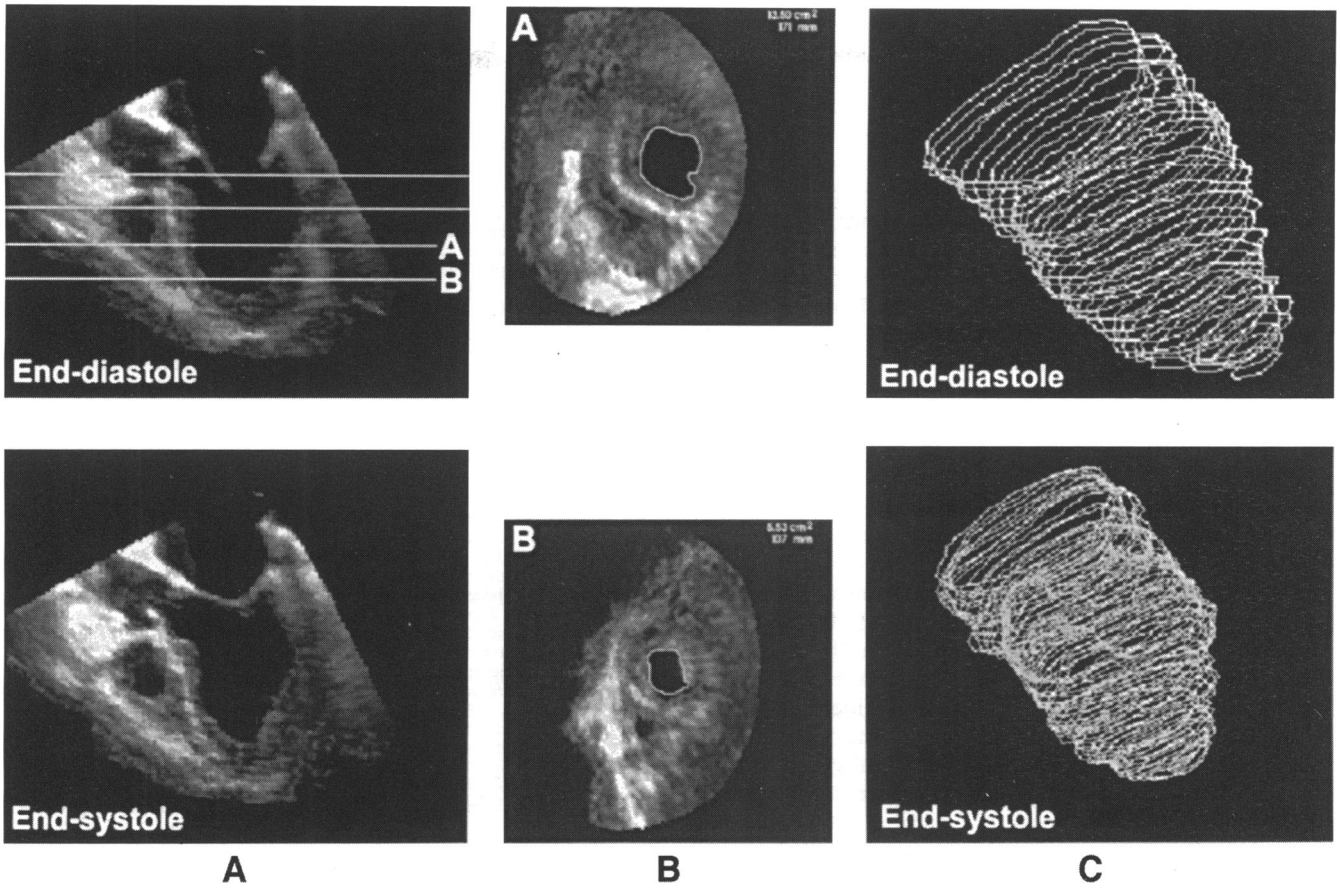

Figure 2 Principle of left ventricular volume calculation using a three-dimensional data set (paraplane echocardiography). An end diastolic long axis view is selected as a reference view and the left ventricle is sliced at equidistant intervals to generate a series of short axis views (B). The contours of the left ventricular cavity are planimetered and the volume of each slice is calculated. Adding up the volumes of all slices provides an accurate volume measurement of the left ventricle (Simpson's rule). This is performed for both end diastolic and end systolic data sets. The figure shows an end diastolic long axis view (A) with three lines indicating the short axis views shown in the panels B. Panels C show reconstructions of the left ventricle using the planimetered contours of short axis views obtained every 3 mm.

scanning are inefficient for the precordial acoustic windows, which require a small transducer. Small rotatable-array (multiplane) transoesophageal transducers now allow the recording of sequential high-resolution cross-sections from a single and fixed transducer position.[6] The rotational approach can also be used at a single pivot point over a precordial acoustic window: probe assemblies that can accommodate standard transducers have recently been constructed.[7] Image acquisition is controlled by a software-based steering logic which allows for variations in the cardiac and respiratory cycles. Images of a complete cardiac cycle are recorded at 25 frames/s, digitised, and formatted in isotropic data sets into the correct sequence according to their electrocardiographic phase. This allows the dynamic display of the three-dimensional images and selected cross sections in a cine-loop format.

All the ultrasound data are used to provide three-dimensional reconstructions with grey scale information about the tissue. However, the generation of good quality three-dimensional reconstructions by the precordial approach remains challenging because of difficulties in obtaining the required high quality images in multiple orientations. Therefore, the transoesophageal approach, by circumventing the chest wall and by using higher transducer frequencies, currently provides the best results.[6 7]

Three dimensional echocardiography may become, after further refinements, the ultimate diagnostic imaging technique because it can display the cardiac structures, their size, shape, and abnormalities in motion from any perspective. The echocardiographic examination procedure will become standardised and less dependent on the operator's skills. Cardiac cross-sections that are difficult or impossible to obtain from the "old" precordial or transoesophageal acoustic windows can be computed from the data set in any desired plane (*anyplane echocardiography*) and shown in a cine-loop format. This facility offers new perspectives for diagnosis. The images needed for diagnosis are often only part of the total three-dimensional image set and appropriate regions of interest imaged in the living patient can be extracted or structures of interest removed from their surroundings for detailed analysis. With presently available technology, details of internal cardiac anatomy are already well visualised. The right ventricle, the atria, aneurysmal left ventricles in patients with coronary artery disease, and complex congenital heart disease[8] are obvious examples where mental conceptualisation is difficult. Measurement of these structures is now possible. Three-dimensional images can be generated to show aortic and mitral valve lesions (fig 1), prosthetic valves, and mass lesions in projections not available with standard two-dimensional echocardiography.

Surgeons can preview what they will find during surgery (*electronic cardiotomy*) and gain information on function.[9] This will be of particular help in valve and congenital defect repair. Eventually, a physical replica of

the patient's heart could be produced to show complex pathology from any desired perspective.

Probably the greatest advantage will be the generation of images for accurate measurement. New software already allows simple dimensional measurements directly in the voxel volume. It will no longer be necessary to make geometric assumptions to calculate left and right ventricular volumes and it will be possible to calculate size and shape by using a series of computer generated cross-sections encompassing the whole heart rather than using one or two orthogonal planes. Parallel slicing through the volume data allows equidistant cross-sections to be produced at selected intervals in any direction (*paraplane echocardiography*). This permits accurate measurements of the volumes of the cardiac chambers and the areas of the valve orifices (fig 2). The new quantitative indices that will be studied will expand the range of clinical problems that can be solved.

At present, computer reconstruction takes a long time. It takes up to 45 minutes to generate a three-dimensional image of a specific structure so three-dimensional reconstruction is not done routinely. Increasing clinical utility together with shorter processing time and easier and faster display of the three-dimensional images will stimulate its more widespread use. We need guidelines for the standardisation of views including conventional orientations, surgical views, and non-conventional views in various disease categories.[10] Three-dimensional echocardiography is set to become a clinical tool providing unique diagnostic information and leading to new approaches to quantitative analysis. These advances are likely to improve treatment.

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